Statistical Forecasts of 24, 48 and 72 h Typhoon and Tropical Storm Intensity Changes

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(Manuscript received 4 October 1974, in revised form 31 January 1975)

ABSTRACT

A 10 year (1960–69) sample of observations in western North Pacific tropical cyclones over open ocean was used to derive statistical regression equations to forecast the maximum wind speed for 24, 48 and 72 h periods. Stratification of the dependent data by latitude bands, by months, and by maximum intensity were tested with both five-predictor and ten-predictor equations. An independent sample of tropical cyclones (July, August and September of 1955–59) was used to test the derived regression equations. Verification was in terms of the relative forecast error according to the acceptability criteria set by the Joint Typhoon Warning Center, Guam.

Equations derived from a combined dependent sample of July, August and September storms stratified into two bands (one north, one south of 20°N) produced forecasts which were equivalent or superior to equations derived from storms stratified by months or in three 10° bands from 5°N to 35°N. These two five-predictor equations for the 24 h period were also superior to equations derived for storms within the classes $\leqslant 65$, 66–100 and $\geqslant 101$ kt. Although not tested with a homogeneous set of forecasts using operational data rather than post-season data, the objective forecast technique appears to give results comparable to or better than recent official intensity forecasts, especially for the 72 h interval.

1. Introduction

Much of the attention in tropical cyclone forecasting has been devoted to prediction of the movement of the storm, because the damaging winds near the center frequently occur on a space scale smaller than the error in forecasting the location of these winds. In these situations it was sufficient to predict the general stage of development. As track forecasts have improved, the intensity characteristics assumed more importance, and several aids for the typhoon forecaster have been developed. One of the earliest objective techniques was developed by Arakawa (1961, 1963) as an adjunct to statistical equations for calculating the movement of typhoons. The surface pressures observed in a grid moving with the storm and various other descriptive parameters were used as predictors for central pressure values. Gray (1970) has recently prepared a summary of climatological characteristics of western Pacific tropical cyclones including various factors favorable for intensification. Riehl (1972) discussed the intensity changes of recurved typhoons.

Tables of 12, 24 and 48 h intensity changes of tropical cyclones in 10°×10° latitude/longitude areas of the western North Pacific were presented by Brand and Gaya (1971) for various seasons and stages of development. These statistics were based on a history file of tropical cyclones from 1945–69. The same file has been used to examine storms which might be expected to deviate from the climatological intensity changes given by Brand and Gaya (1971). For example, Brand and Blelloch (1973) describe the intensity changes as the storms cross the Philippines. Also, Brand (1973) has indicated the seasonal distribution and locations of rapidly intensifying storms (increase of maximum wind speed of 50 kt or more in 24 h) and low-latitude (south of 25°N) storms which weakened by more than 20 kt in 24 h. Holliday (1973) has also studied various cases of rapidly intensifying tropical cyclones in the western Pacific.

Satellite pictures have been used for some time to estimate the maximum wind speed in tropical cyclones based on the technique of Hubert and Timchalk (1969). Dvorak (1973) has extended this approach to forecast 24 h changes in maximum intensity based only on characteristics of the satellite pictures. This technique shows considerable promise for short-term forecasts of tropical cyclone intensity. Future progress toward accurate intensity forecasts will probably come as a result of combinations of satellite and other objective schemes as suggested by Simpson (1971) and Hebert (1973) for Atlantic hurricanes.

The purpose of this study was to use a portion of the western North Pacific history file to develop objective techniques of forecasting 24, 48 and 72 h tropical cyclone intensity changes over open ocean. An independent subset of storms was used to verify the stability of the derived statistical regression equations.

2. Data sources

The data used in this study were extracted from the history file of tropical cyclones of the western North Pacific during the period 1945–69, compiled by the National Climatic Center for and with the Naval Environmental Prediction Research Facility [see Brand and Gaya (1971) and Brand (1973)]. The original tape contained 18 parameters used to forecast movement by an analog technique (Jarrell and Somervell, 1970). Included within the history file are six-hourly information based on post-season analysis of storm characteristics such as location, movement, size and intensity. The only upper-air data included in the history file is at 700 mb, because this is the most common reporting level for the reconnaissance aircraft. Unfortunately, data from higher levels are generally lacking, especially during the early period. For the purposes of this study, the measure of storm intensity will be maximum wind speed (kt), rather than the minimum sea level pressure. The reported values of maximum intensity were taken to be typical of the peak winds averaged around the storm, because post-season data are normally smoothed. The central pressure is usually thought to be a more conservative intensity parameter in an individual storm because the reconnaissance flight eye-penetration may not have penetrated through the highest wind speed region. However, the use of winds as the intensity parameter eliminates the additional step required to convert a predicted central pressure value to a maximum wind speed estimate.

Only the data from the last 15 years on the file were used in this study, since the wind data would be more accurate in this period, especially after the introduction of Doppler radar navigation. Observations from storms during 1960–69 formed the dependent data sample, and those occurring during July through September of 1955–59 were used as independent data to verify the statistical equations. Only storms over the open ocean east of 125°E were selected, terminating with the observations 6 h prior to the storm striking land. Storms which were not observed during the intensification stage were also eliminated from the test sample, as were those few storms which had a northeasterly heading throughout their existence.

Some of the predictors involve changes which occur over the 24 h preceding the issuance of the forecast. Thus there was a requirement for a 48, 72 or 96 h history to enable forecasts of 24, 48 and 72 h. For example, a storm lasting 96 h would contribute only one case to the 72 h dependent data sample. In addition to greatly reducing the sample size, this might have resulted in elimination of some of the more difficult forecasts either early or late in the lifetime of the tropical cyclone. The sample of intensity changes for the longer period forecasts was probably distorted because the decay cycle of many storms was not included, especially if the track was over land.

3. Development of the regression equations

As indicated above, the history file contained a number of parameters characterizing the storm and certain large-scale synoptic variables thought to be important in selecting analogs for movement forecasts. These variables, excluding past 48 h movement and speed, are listed in the Appendix. Various combinations of these variables were also included within the final list of 39 predictors. Most of the new variables include ratios or differences of the maximum intensity with the other parameters. Several of the predictors require knowledge of the parameters during the previous 12 or 24 h period. No predicted variables, such as the future location or future synoptic parameters, were included as predictors. The regression equations were developed in a stepwise manner, adding in each step the variable that makes the greatest reduction in the error sum of squares [see BIMED 02R from Dixon (1966)].

One might expect that it would be useful to stratify the data to isolate some of the important factors which may determine the intensity changes in the storm. For example, the potential instability necessary to develop and sustain a typhoon is normally associated with the sea surface temperature. While these temperatures are not available in the history file, the main orientation of the isotherms is east-west. The climatological intensity changes shown by Brand (1973) also suggest strong variations across latitude bands. As it was not obvious how the latitude bands should be chosen, equations were developed for two bands (one north, and one south of 20°N) and for three 10° latitude bands between 5°N and 35°N. Another grouping of the data was by months or seasons, because the average maximum intensity varies with season. [Liechty (1972) used the same data set to demonstrate the monthly variation.] Stratification by the present maximum intensity of the storm was suggested by Brand and Gaya (1971). On visually scanning the data, values of 65 and 100 kt seemed to recur. Other authors (e.g., Fung, 1970) have noted a tendency for the tropical cyclone central pressures to occur in three categories. Thus the "plateau" values were used to define three intervals, $\leqslant 65$ kt, 66–100 kt and >100 kt.

DISCUSSION OF REGRESSION EQUATIONS

Summaries of the six combined July–August–September regression equations (see Appendix) which are proposed as the forecast technique are shown in Table 1. Similar information was obtained for other regression equation sets which were derived for the various stratifications discussed above. In many cases the multiple correlation coefficient was considerably higher than shown in Table 1, but this set of regression equations provided the best forecasts when applied to the independent sample.

The mean intensity change and the corresponding sample standard deviations (σ) shown in Table 1 increased with the length of forecast interval. It was expected that the mean intensity changes for storms south of 20°N would be positive, because this is predominantly a tropical cyclone genesis region. The storms tend to reach maximum intensity and decay north of 20°N, resulting in negative mean intensity changes. Even though the number of forecasts in each latitude band was approximately the same, the negative values were not as large, since part of the decay phase of the storms was not sampled. The standard deviations were larger than the mean values, indicating about one-fourth of the storms decayed south of 20°N, and nearly one-half of the storms intensified north of 20°N. If the intensity changes were normally distributed about the mean, one would expect about 68% of the intensity changes to be contained within a range about the mean of twice the standard deviation or about 40, 60 and 70 kt for the 24, 48 and 72 h forecasts, respectively. These ranges of observed intensity changes indicate the difficulty of the forecast problem.

The variance in the dependent sample which is explained by the five-predictor, combined July–August–September regression equation would be indicated by the squares of the multiple correlation coefficients in Table 1. It is somewhat surprising that the explained variance increased with the longer period forecasts. However, even in the 72 h cases less than 55% of the variance was explained. The standard error of the regression equation estimate increased with the length of the forecast period as in the case of the sample standard deviation. The error does not increase linearly with time, so that the error per forecast hour decreases.

TABLE 1. Summary of dependent sample of maximum intensity changes (kt) in western North Pacific tropical cyclones. Multiple correlation coefficient (r) and standard error (S.E.) of estimates by five-predictor regression equations based on a combined July–August–September sample and by a forecast of persistence (of intensity change). S.S., sample size; σ, standard deviation.

				July–August–September equations		Persistence forecasts	
Latitude	S.S.	Mean	σ	r	S.E.	r	S.E.
			24 h forecasts				
<20	546	12.7	21.2	0.63	16.5	0.37	19.8
⩾20	673	−2.2	20.1	0.59	16.2	0.28	19.3
			48 h forecasts				
<20	494	21.8	33.6	0.65	25.6	0.16	33.2
⩾20	497	−7.7	28.1	0.64	21.6	0.13	27.9
			72 h forecasts				
<20	398	24.2	39.3	0.73	27.1	0.02	39.3
⩾20	345	−10.2	33.7	0.74	23.0	0.01	33.8

TABLE 2. Variables which appeared in five-predictor, combined July–August–September regression equations for 24, 48 and 72 h forecasts of intensity change.

Storm south of 20°N

Latitude, longitude, maximum intensity, size, 12 h changes in maximum intensity and sea level pressure, 24 h changes in latitude and maximum intensity.

Storm north of 20°N

Longitude, maximum intensity, sea level pressure, 12 h changes in maximum intensity, size, sea level pressure and latitude, 24 h rate of movement, 700 mb ridge latitude.

The correlation coefficients between the past 24 h intensity change and the 24, 48 and 72 h future intensity changes are also shown in Table 1 for comparison with the five-predictor regression equations. These are labeled as *persistence* forecasts as the past intensity change was multiplied by 1, 2 and 3, respectively. The correlation coefficient for these forecasts decreased with time, until at 72 h almost none of the variance in the sample was explained by the persistence forecasts. In each case the regression equations were superior to the persistence forecast.

While the regression equations may be found in the Appendix, it is of some interest which of the 39 variables were selected, and thus what information will be required to apply the forecast scheme. The variables necessary for a 24, 48 and 72 h forecast of a storm north or south of 20°N are listed in Table 2. Not all of these variables are used in each equation, and they may appear as squares, ratios or differences. The 24 h forecast equations do not require the past 24 h changes in variables shown in Table 2, and therefore may be applied with only 12 h history. It is surprising that both the 12 h change in maximum intensity and in sea-level pressure entered for the storms south of 20°N as these changes are highly correlated. The selection of latitude as a predictor in the equations for storms south of 20°N led to the additional tests involving stratification into three bands. Likewise the importance of the present maximum intensity as a predictor in various forms suggested the stratification according to maximum intensity. Movement parameters were selected in each equation for a storm north of 20°N, and in the 72 h equation for storms south of 20°N. The radius of the outermost closed isobar was the only synoptic parameter which entered in the equations south of 20°N, and only in the 24 h equation. The 700 mb ridge latitude must be known to apply both the 48 and 72 h equations north of 20°N.

4. Tests with independent data

It is somewhat difficult to interpret the usefulness of the derived regression equations based only on the correlation coefficients and standard errors in Table 1. Consequently, the regression equations were tested using the verification technique of the Joint Typhoon Warning Center, Guam (1971 Annual Typhoon Report). The acceptability criteria for disaster control planning are specified as a relative percentage error of the verifying maximum wind. As shown in Table 3, larger errors are considered tolerable for a 48 or 72 h outlook compared with a 24 h forecast. The verification statistics for 1971 shown in Table 3 indicate about 25% of the official intensity forecasts/outlooks were accurate, and roughly 75% were considered useful. The remaining 25% of the intensity forecasts would be considered misleading. Although these statistics may include forecasts of storms not over open ocean, this will be the standard for evaluating the usefulness of the objective intensity forecasts. It should be emphasized that regression approaches such as tested here can only be expected to predict the "normal" intensity changes. The abnormal situation, such as unusual strength or rate of intensification/decay, is not handled well by statistical approaches.

a. Stratification by latitude

The verification of the set of six regression equations described above was with two samples of storms selected from the history file in the same manner as the July–September 1960–69 dependent data sample. The results for the first independent sample of July–September 1955–59 storms (see Table 4) prompted an additional test using storms during May, June, October and November, 1960–69. Results for persistence (of intensity change) forecasts are also shown in Table 4.

A general comparison with the official forecast statistics for 1971 (Table 3) indicates that the objective scheme is superior. At 24 h about 46% of the nearly 1500 objective forecasts in the two samples verified in the accurate category (within 10% of the verifying maximum wind). Furthermore between 85–90% of these objective 24 h forecasts would be classified as useful (less than 30% relative error) by the acceptability criteria set by JTWC. As expected, the percentage of forecasts within 10% relative error (accurate category) decreased with forecast interval, although about 30% of the 72 h forecasts fell in this category. Considerable skill remains in the 48 and 72 h ranges as about 80% of the objective forecasts were useful.

TABLE 3. Distribution (percent) of 1971 official intensity forecasts for typhoon and tropical storms verifying in the acceptability classes shown (from 1971 Annual Typhoon Report).

Acceptability class (relative error)	Official forecast 24 h	48 h	72 h
Accurate (within 10%)	25%	24%	24%
Adequate (≤20% at 24 h; ≤30% for 48, 72 h)	55	64	59
Useful (≤30% at 24 h; ≤40% for 48, 72 h)	72	77	65

TABLE 4. Distribution (percent) of objective intensity forecasts for independent data using the best set of regression equations stratified by latitude. S.S., sample size.

	Sample I*		Sample II*	
	Objective	Persistence	Objective	Persistence
		24 h forecasts		
Accurate	47%	32%	46%	38%
Adequate	77	58	74	61
Useful	90	73	85	75
S.S.	585		881	
		48 h forecasts		
Accurate	27%	14%	31%	16%
Adequate	74	42	71	48
Useful	88	53	80	59
S.S.	435		668	
		72 h forecasts		
Accurate	31%	9%	30%	12%
Adequate	70	31	66	29
Useful	82	58	78	39
S.S.	302		481	

* Sample I: July–Sept., 1955–59; Sample II: May–June, Oct.–Nov., 60–69.

The persistence forecasts also showed a decay in skill with forecast interval, with about 50% useful (and 50% misleading) in the 48 and 72 h forecasts. Recall that the 48 and 72 h persistence forecasts had very small correlation coefficients in the tests with dependent data. In the 24 h time frame, extrapolating the intensity change produces results quite similar to the official forecasts (Table 3). This may indicate that the actual forecast situations are generally more difficult, since one would expect an improvement over a persistence intensity change due to subjective modification by experienced forecasters. On the other hand, the persistence forecasts in Table 4 had the advantage of being based on best estimates of actual intensity after post-season analysis. Extrapolation from these smoothed data would certainly be an improvement over taking differences of the operational estimates of actual intensity. It should be realized that a degradation of the statistical regression technique will also occur in an operational application. However, subjective modification of the objective forecasts in instances with unrealistic intensity changes would also improve the scheme. A test using only the data available to the forecaster will be necessary to evaluate these points.

As indicated earlier, the set of six regression equations are stratified only for latitude bands north or south of 20°N, and were derived for a combined July–September sample. No advantage was gained by using monthly equations versus the combined sample equations. The results with the independent sample from May, June, October and November, 1960–69, suggest that this set of equations can be used during most of the typhoon season. Tests with the independent sample using a separate set of regression equations derived in three 10° latitude bands also did not produce superior forecasts.

In addition, ten-predictor equations were derived and tested in expectation that the additional predictors would improve the forecasts for longer time intervals. However, the differences were typically only 1–2% and were not statistically significant. Thus it appears that the set of six, five-predictor equations is not only convenient for operational use, but gives results comparable to the more highly stratified equations.

b. *Stratification by initial intensity*

The consistent appearance of the maximum intensity as a predictor in the regression equations suggested a primary stratification by the present maximum intensity, rather than by month or by latitude. Regression equations were developed from the combined dependent sample of July, August and September storms for the maximum intensity classes $\leqslant 65$, 66–100, $\geqslant 101$ kt. These equations were then tested on a similarly stratified set of independent data from 1955–59 (see Table 5). In addition to presenting the results as relative forecast errors corresponding to the acceptability classes in Tables 3 and 4, the percent of the forecasts which verified within 10, 20 and 30 kt are also shown. Two conclusions can be drawn from this test. First, the percentages of the 585 independent sample forecasts using equations stratified by present maximum intensity verifying within 10, 20 and 30% are essentially equivalent to the results shown in Table 4 for the 24 h equations stratified by latitude. As each equation set is based on the same dependent sample, the stratification in three intensity classes does not have any advantage over the two latitude-band equations. Second, the use of a relative forecast error in the JTWC acceptability criteria introduces an apparent distortion for the storm class with maximum winds $\leqslant 65$ kt. Only about one-quarter of these storms verify within 10%, whereas about 50% of the more intense storms verify in the 10% category; and the bias remains in the 20 and 30% categories. This is clearly due to the use of a relative error versus an actual error, as shown in Table 5. When evaluated in categories of $\leqslant 10$, $\leqslant 20$ and $\leqslant 30$ kt actual errors, the verification of the objective forecasts does not appear to be dependent on the intensity class.

Use of the JTWC acceptability criteria, with the usual mental substitution of 10 kt for a 10% forecast error in a typical typhoon, will lead to an underestimate of the forecast scheme ability in about one of every four cases. To eliminate the bias between seasons with a different distribution of storm intensity, it would be preferable to replace the criteria with actual speed changes: $\leqslant 10$ kt (accurate), $\leqslant 20$ kt (adequate, $\leqslant 30$ kt (useful). Of course evaluation of the schemes by the original criterion will not be changed, but the suggestion that a 20 kt intensity forecast would be misleading if the storm verified at 15 kt is questionable. The history file contains a number of such weak storms although current practice is not to make forecasts beyond 24 h if the maximum wind speed is below 30 kt.

TABLE 5. Distribution (percent) of 24 h intensity forecasts of July–September 1955–59 independent data using regression equations stratified by present maximum intensity.

Forecast error	Maximum intensity $\leqslant 65$ kt S.S. = 142	 66–100 kt S.S. = 282	 >101 kt S.S. = 161	 All S.S. = 585
$\leqslant 10\%$	26	50	47	43
$\leqslant 10$ kt	46	53	42	48
$\leqslant 20\%$	55	75	84	73
$\leqslant 20$ kt	82	79	70	77
$\leqslant 30\%$	73	90	91	86
$\leqslant 30$ kt	94	92	90	92

5. Conclusion

A ten-year sample of observations of western North Pacific tropical cyclones over open ocean was used to derive a set of six regression equations (shown in the Appendix) to forecast the maximum wind speed changes over 24, 48 and 72 h periods. These six equations were based on a combined sample of July, August and September storms stratified into two bands north and south of 20°N. When verified with an independent five-year sample of July–September storms, the combined sample regression equations forecasts were equivalent or superior to equations derived from storms stratified by months or in three 10° latitude bands. These same equations also have skill in predicting intensity changes for storms occurring between May and November although it may not be assumed that the equations are the optimum ones for this entire period. In general, such objective techniques seem to show ability in forecasting changes in the normal situations, but do not handle the abnormally rapid intensification or decay situations. Further optimization of these techniques may result in only small gains compared with developing skill in recognizing the abnormal situation. The objective technique results appear to be superior to recent verifications of official forecasts, although this should be verified with a sample based on operational data.

Regression equations were also derived for storms stratified by present maximum intensity in classes $\leqslant 65$, 66–100, $\geqslant 101$ kt. In a test of 24 h intensity changes these equations did not improve on the two latitude-band equations. This stratification did illustrate the bias in the acceptability criteria of the Joint Typhoon Warning Center, Guam, toward more intense storms. Forecasts of weak storms must meet overly restrictive accuracies compared with forecasts of intense storms. From this viewpoint, a more equitable verification scheme would seem to be the use of the actual wind speed errors rather than the relative errors.

Acknowledgments. This research was supported by the Environmental Prediction Research Facility, Monterey, Calif. S. Brand provided the history file of tropical cyclone observations and offered many helpful suggestions during the course of the research. E. J. Harrison, Jr., and W. van der Bijl made numerous suggestions on the manuscript. Additional constructive comments by F. L. Martin, J. Jarrell and L. Craiglow are gratefully acknowledged. The computations were done at the W. R. Church Computer Center of the Naval Postgraduate School. Ms. M. Marks very ably typed the manuscript.

APPENDIX A

Regression Equations

The variables (shown with asterisks) available as predictors in the regression equation were obtained from a history file prepared by the National Climatic Center in cooperation with the Environmental Prediction Research Facility, Monterey. Additional predictors were formed as differences, squares and ratios of the original variables. Although there is some ambiguity, the predictors may be grouped as follows:

Location and movement parameters
1* Latitude (degrees and tenths)
2* Longitude (degrees and tenths)
3* 12 h direction (deg)
4* 12 h speed (kt)
5* 24 h direction
6* 24 h speed (kt)
7 12 h latitude change
8 12 h longitude change
9 24 h latitude change
10 24 h longitude change

Intensity parameters
11* Minimum sea level pressure (mb)
12* 12 h change in sea level pressure (mb)
13* Maximum wind speed (kt)
14* Minimum 700 mb height (dm)
15 12 h change in maximum wind speed
16 24 h change in maximum wind speed
17 Maximum wind speed minus sea level pressure
18 Maximum wind speed/size
19 12 h change in maximum wind speed +10
20 Maximum wind speed squared
21 Maximum wind speed squared/size
22 Maximum wind speed/sea level pressure
23 24 h speed/maximum wind speed
24 24 h change in maximum wind/size
25 12 h change in maximum wind +10÷12 h change in size +10

Storm characteristics
26* Size, radius of outer closed surface isobar (degrees latitude)
27* 12 h change in size
28 12 h change in size +10
29 700 mb minimum height minus sea level pressure

Synoptic parameters
30* 700 mb ridge latitude (deg)
31* 700 mb ridge height (dm)
32* 700 mb trough longitude (deg)
33* 700 mb trough height (dm)
34 700 mb ridge latitude minus storm latitude
35 700 mb ridge height minus minimum 700 mb height
36 Parameter 35÷Parameter 34
37 700 mb trough height minus minimum 700 mb height
38 700 mb trough longitude minus storm longitude
39 Parameter 37÷Parameter 38

The regression coefficients to predict the intensity change (kt) for tropical cyclones are as follows:

Cyclones south of 20°N

24 h		48 h		72 h	
Parameter	Coefficient	Parameter	Coefficient	Parameter	Coefficient
constant	−44.63	constant	−76.03	constant	−27.22
2	0.38688	1	−2.2153	1	−2.68780
12	−0.48747	2	0.81136	2	0.81984
15	0.58992	13	0.87452	9	−5.27374
18	0.63176	16	0.27168	16	0.59890
21	−0.00867	20	−0.00689	20	−0.00356

Cyclones north of 20°N

24 h		48 h		72 h	
Parameter	Coefficient	Parameter	Coefficient	Parameter	Coefficient
constant	6.57	constant	−229.8	constant	−433.29
7	−3.30801	2	0.40449	2	0.72003
12	−0.45188	7	−7.00774	12	−0.48052
17	−0.00373	17	−0.25390	17	−0.45355
20	−0.00063	25	3.73032	23	−66.63809
25	4.98910	30	−1.61691	30	−2.03917

APPENDIX B

An Operational Test

The objective forecast scheme described in this paper was evaluated during the 1974 typhoon season at the Joint Typhoon Warning Center, Guam. Intensity forecasts were generated on an irregular basis from the 24, 48 and 72 h regression equations using real-time data. These completely objective forecasts were verified against post-analysis intensities for eight storms that achieved typhoon intensity. To be consistent with the dependent sample used to generate the regression equations, all forecasts that verified after the storm passed over land were eliminated.

The average magnitude of forecast errors is summarized in Table B1 for the objective scheme and the official (JTWC) forecasts. The number of cases in the homogeneous sample is quite small, as the objective scheme was not available for each 6 h forecast cycle. Verifications for the larger non-homogeneous sample of official forecasts are also included for comparison. A consistent growth in average error with increasing interval is indicated for both objective and official forecasts, but the error growth is much smaller for the objective scheme. At least for this small sample, the objective forecasts are superior to the official forecasts in every category. Thus the preliminary operational tests indicate results similar to the tests in the research mode.

Because a large fraction of the 1974 storms crossed the Philippines, the objective scheme was also evaluated after the storms passed into the South China Sea. The 24 h average errors were 18.9 and 20.6 kt for the 28 forecasts in the homogeneous sample of objective and official forecasts. Corresponding values for the 48 h period were 19.1 and 21.8 kt for only 11 cases. Although the objective scheme again appears superior for this additional sample, the differences are too small to be convincing.

TABLE B1. Average magnitude (kt) of errors for sample* of intensity forecasts initiated east of 125°E that verified over water (without striking land during forecast).

	Forecast period		
	24 h	48 h	72 h
Homogeneous sample			
Objective	10.2	10.6	11.3
Official	12.8	12.7	24.8
Number	52	22	21
Non-homogeneous sample			
Official	11.3	16.5	23.0
Number	107	68	41

* Sample included typhoons Bess, Carmel, Della, Mary, Polly, Elaine, Irma and Gloria.

Since the objective scheme was in an evaluation phase, and presumably was not calculated for each 6 h period, it is assumed that the official and objective samples are independent. The official forecasts are subjective, with guidance from the Dvorak (1973) scheme for 24 h forecasts, an analog scheme (developed by L. Craiglow at JTWC), and climatology. The above results indicate that the objective scheme based on regression equations will provide a useful tool for the typhoon forecaster.

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